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Analysis of Thermal and Electrical Properties of Enamel Filled with Various Nanofillers such as ZrO_2, Al_2O_3 and CNT

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Abstract: ***The last decade has witnessed significant improvement in the area of nanofillers on electrical, thermal and mechanical properties of polymeric materials. The dielectric and thermal properties of standard enamel and various nanofiller mixed enamel were detailed and analyzed. Nanopowders of ZrO_2, Al_2O_3 and CNT were used as filler. Ball Mill was used to synthesize nanofillers of ZrO_2 and Al_2O_3. CNT were synthesized by the process called chemical vapour deposition (CVD). The basic dielectric properties such as dielectric strength, partial discharge characteristics and thermal withstand strength of the enamel filled with various nanofillers such as ZrO_2, Al_2O_3 and CNT at various proportions (1%, 3% and 5%) were analyzed and compared with the properties of the standard enamel. The experimental results show that enamel mixed with various nanofillers has higher thermal properties when compared to that of standard enamel.***

Key words — CNT, ZrO_2, Al_2O_3, chemical vapour deposition, Ball Mill, dielectric strength and partial discharge.

1 INTRODUCTION

In the last few years, a great deal of attention has been given to the application of nanodielectrics in the field of electrical insulating materials. It has been reported that the use of nanoparticles in the matrix of polymeric materials can greatly improve the thermal, mechanical and electrical properties of polymeric nanocomposites [8]. Insulating materials play a significant role in the design and performance of high voltage systems. They can be used for insulation purposes, cooling purposes and mechanical support [7]. Despite the basic understanding of electrical breakdown of materials, electrical surface flashover phenomena, physical mechanisms responsible for the initiation of such unwanted electrical activities within an insulation system composed of such advanced materials must be investigated before they can be commercially available [11]. The findings of such studies were essential for the development of nano-electric and other advanced materials and the techniques to predict the reliability of the advanced electrical systems which utilize these materials.

The nanostructured polymeric materials are object of great interest by the researchers. The reasons of this interest were well-known: several mechanical, thermal and electrical properties can be improved by adding few percent of inorganic "nanofiller". But as regards barrier properties these materials gave the best results [3]. This paper focused on the characterization of dielectric and thermal properties of standard enamel and various nanofillers mixed enamel.

2 EXPERIMENTAL

2.1 Sample Preparation

The nanocomposites were prepared by radical initiator curing method. Diamino Diphenyl Methane (DDM) was used as curing agent. The DDM was melted at 60° - 80°C for 10 minutes. The enamel, resin and melted DDM were mixed in a beaker. The mixture was poured into the die coated by a Teflon sheet. The die was heated at 120° C for 3 hours. Then, the die was taken away from the oven and it was cooled for 1 hour. Ten different samples were produced [8]. The process involved for preparation of nanocomposites was revealed in Figure 1.

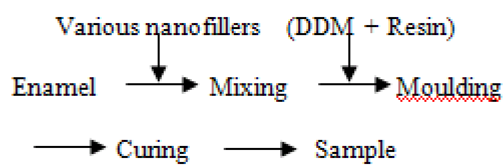

Figure 1. Sample Preparation

2.2 Synthesis of carbon nanotubes

The synthesis of carbon nanotubes consists of three stages: Preparation of Catalysts for carbon nanotubes, Chemical vapour deposition (CVD) process shown in figure 2 and Purification of Carbon Nanotubes. The micropowders of ZrO_2

and Al_2O_3 were converted into nanopowders by using Ball mill method.

Figure 2. Experimental setup of CVD system

The particle size of the powder was analyzed by using the SEM characterization techniques. From the results, the particle size was found to be tens of nanometer.

2.3 Partial Discharge Measurements

The partial discharge experiment was carried out inside the shielded room to avoid the external noises. Figure 3 shows the circuit arrangement for the partial discharge measurement. The different samples were placed between the electrodes and the whole electrode setup was kept inside the oil to avoid gliding discharge between contacts. The voltage was applied gradually. The initial discharges occurring in the samples were captured by a high quality oscilloscope. The inception and extinction voltages were noted.

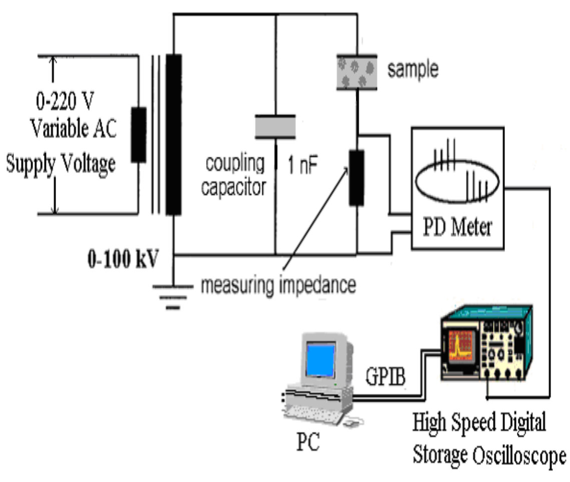

Figure 3. Circuit diagram for Measurement of Partial Discharge

A standardized testing arrangement with electrode setup for the determination of the breakdown (BD) voltage and partial discharge (PD) inception and extinction voltage of solid samples as per standard (IEC 60243 – 1) was shown in figure 4.

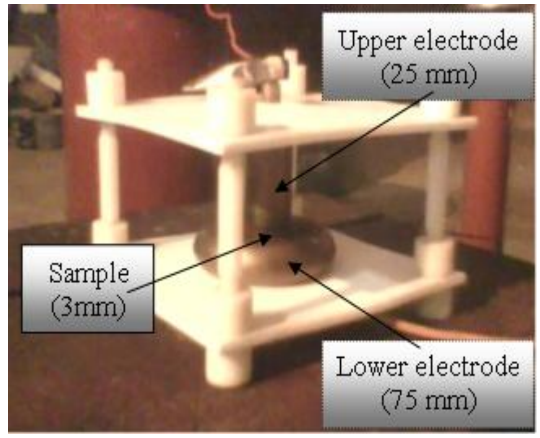

Figure 4 . Electrode setup for BD and PD measurement

2.4 Dielectric Strength Measurements

The dielectric strength test was conducted with alternating voltage, which should be increased from zero to the breakdown value. The voltage was applied to the samples by means of a high voltage transformer. The value of the voltage at which breakdown occurs in the sample was noted. The sample thickness was 3mm and the diameter of upper electrode was 25mm and the diameter of lower electrode was 75mm [1].

2.5 Thermo Gravimetric Analysis (TGA)

Thermo gravimetric analysis was a simple analytical technique to measure the weight loss or weight gain of a material as a function of temperature. The TGA results have been obtained from diamond TG/DTA 6000 instrument system. The sample of 0.1 mg to 10 g was taken and the heat was applied at a rate of 0.1 - 50°C/min. The temperature was maintained in the range of 50°C to 900°C to maintain consistent heating rate and gas flow. Sampling purity, reaction rate, identification, activation energy and heat of reactions were measured using this instrument.

3 RESULTS

3.1 Analysis of Nano-scale Structure

Figure 5, 6 and 7 shows the SEM analyzed image results. These results show that particles were in the form of nano

metric range. The sizes of the particles were in the range from 50 to 120 nm size.

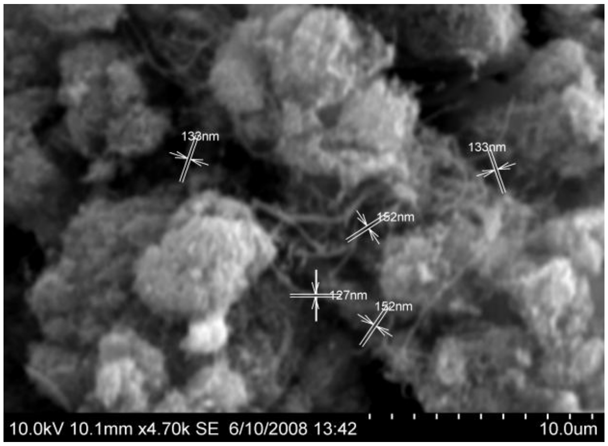

Figure 5. SEM analysis of Carbon nanotubes

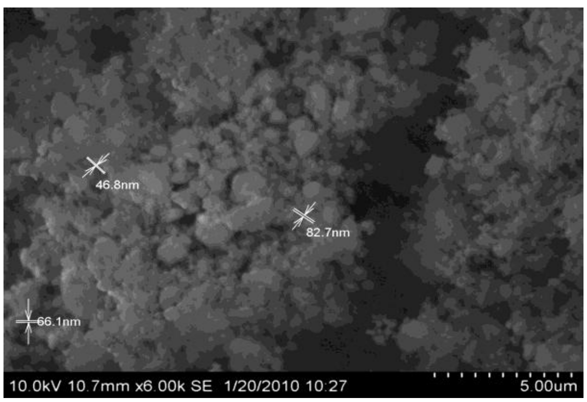

Figure 6. SEM analysis of Alumina Showing nm

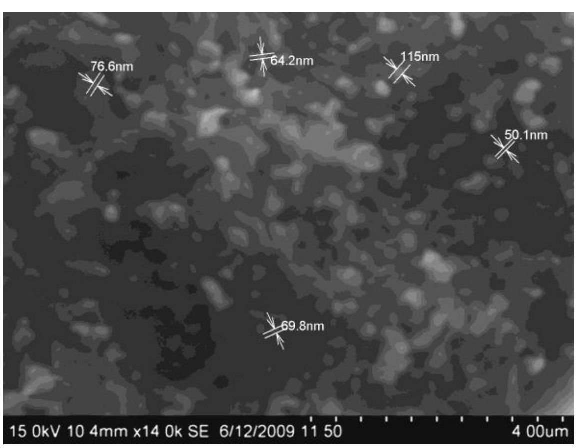

Figure 7. SEM analysis of zirconia

3.2 Partial Discharge Measurement

Partial discharges were in general a consequence of local electrical stress concentrations in the insulation or on the surface of the insulation. A wide group of discharge phenomena such as internal discharges occurring in voids or cavities within solid or liquid dielectrics, surface discharges appearing at the boundary of different insulation materials, corona discharges occurring in gaseous dielectrics in the presence of inhomogeneous fields and continuous impact of discharges in solid dielectrics forming discharge channels were included as partial discharges. The partial discharge measurement was carried out in uniform field electrode configurations. The different values of PD inception and extinction voltage for uniform field configurations were shown in table 1.

TABLE 1. Inception and Extinction Voltages

Sample	Inception voltage (kV)	pC	Extinction voltage (kV)	pC
Pure Enamel	4.74	55	4.10	1.3
1wt% of CNT filled enamel	3.20	65	2.29	1.4
3wt% of CNT filled enamel	4.21	62	3.73	1.4
5wt% of CNT filled enamel	4.31	66	3.73	1.4
1wt% of ZrO_2 filled enamel	5.6	40	4.6	1.2
3wt% of ZrO_2 filled enamel	5.2	35	4.4	1.3
5wt% of ZrO_2 filled enamel	5.1	33	4.2	1.1
1wt% of Al_2O_3 filled enamel	5.1	66	4.13	1.1
3wt% of Al_2O_3 filled enamel	6.5	63	4.62	1.3
5wt% of Al_2O_3 filled enamel	5.3	68	4.2	1.4

From the results, it is clear that the 3wt% of Al_2O_3 filled enamel sample has higher inception and extinction voltages.

3.3 Dielectric Strength Measurement

The breakdown voltage shows an increasing dependence on the nature and smoothness of the electrode material. The breakdown field strength was an extraordinary important material property for dimensioning an insulation system. The values of breakdown strength for different samples under uniform field configuration were shown in table 2. The 1wt%

of ZrO_2 filled enamel sample has higher value of breakdown strength when compared to other samples.

TABLE 2. Breakdown Strength for Various Samples at Uniform Field Configuration

Sample	Breakdown strength (kV/mm)
Pure Enamel	2.56
1wt% of CNT filled enamel	1.91
3wt% of CNT filled enamel	2.34
5wt% of CNT filled enamel	2.35
1wt% of ZrO_2 filled enamel	3.78
3wt% of ZrO_2 filled enamel	3.48
5wt% of ZrO_2 filled enamel	3.03
1wt% of Al_2O_3 filled enamel	3.26
3wt% of Al_2O_3 filled enamel	3.41
5wt% of Al_2O_3 filled enamel	3.13

3.4 Thermo Gravimetric Analysis (TGA)

The melting point temperatures for various samples were given in the table 3. The result shows that the 5wt% of CNT filled enamel sample has the higher melting point when compared to other samples.

TABLE 3. TGA Result for Various Samples

Sample	Melting temp(°C)
Pure Enamel	551.98
1wt% of CNT filled enamel	569.59
3wt% of CNT filled enamel	589.79
5wt% of CNT filled enamel	595.63
1wt% of ZrO_2 filled enamel	575
3wt% of ZrO_2 filled enamel	554
5wt% of ZrO_2 filled enamel	558
1wt% of Al_2O_3 filled enamel	552.85
3wt% of Al_2O_3 filled enamel	573.94
5wt% of Al_2O_3 filled enamel	569.54

4 CONCLUSIONS

SEM analysis showed that the prepared carbon particles were appearing in the form of nano metric size. This comparative analysis shows the following results:

1. The 3wt% of Al_2O_3 filled enamel sample has higher inception and extinction voltages.
2. The 1wt% of ZrO_2 filled enamel sample has higher value of breakdown strength.
3. The 5wt% of CNT filled enamel sample has the higher melting point.

These results show that the additions of few weight percentages of nanofillers would improve the dielectric and thermal behaviour of the enamel.

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Biography

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